Effects of Continuous Passive Motion and Elevation on Hand Edema

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Key Words: edema • hemiplegia • rehabilitation, hand

The purpose of this study was to evaluate the efficacy of the use of continuous passive motion (CPM) of the digits in combination with limb elevation to reduce hand edema. The effects of 30 min of CPM of the digits with the limb elevated were compared with the effects of 30 min of limb elevation alone. Each of 16 subjects with hand edema of varied etiology received both treatments, one on each of 2 consecutive days. Measures of hand volume, finger circumference, and finger stiffness were taken before and after each treatment. Analyses comparing mean percentage change scores for both treatments showed large and significant treatment effects for all three dependent measures. The findings indicate that, for this sample, CPM with limb elevation may be an effective method by which to reduce hand edema for this patient population.

Hand edema is a problem frequently encountered by medical professionals involved in the rehabilitation of patients with paretic upper extremities and in the rehabilitation of patients following hand trauma or hand surgery (Vasudevan & Melvin, 1979). The presence of edema in the hand alters the viscous component of joint mobility, resulting in joint stiffness that can hinder or restrict motion (Brand, 1985). If the edema is prolonged, it can lead to fibrosis, contracture, pain, inability to accomplish tasks of daily living, and diminished quality of life (Hunter & Mackin, 1984).

One of the most commonly recommended methods of hand edema reduction for patients with paretic hands and for posttraumatic or postsurgical hand patients is limb elevation or elevation of the extremity so that the hand is higher than the elbow, and the elbow higher than the shoulder (Boyce, 1970; Carter, 1983; Hunter & Mackin, 1984). Limb elevation has been recommended for use alone (Carter, 1983) as well as in combination with other treatment methods for edema reduction, including active and passive hand exercise, thermal modalities, massage, and various forms of external compression (Brand, 1985; Hunter & Mackin, 1984; Vasudevan & Melvin, 1979).

Although causal mechanisms and quality of hand edema may vary not only among patient groups but also among patients with similar diagnoses (Exton-Smith & Crockett, 1957; Hurley, 1984), the recommended conservative treatment methods for edema reduction share the common goal of increasing lymphatic and venous drainage from the hand (Vasudevan & Melvin, 1979). Unfortunately, treatment results for patients with paretic upper extremities and for patients with postsurgical or posttraumatic edema that persists beyond the normal healing time are often not satisfactory, and edema persists (Exton-Smith & Crockett, 1957; Witte, Witte, & Dumont, 1984). We must therefore search for more effective methods of hand edema management for these patient populations.

Therapists are now using continuous passive motion (CPM) machines, originally devised to aid in tendon healing and early restoration of motion after surgery (Salter et al., 1984), as a way to reduce hand edema (Petrone & Calvanio, 1989). The use of hand CPM devices for edema reduction follows clinical observations of reduced edema associated with the use of CPM and is based on the rationale that CPM provides a pumping action that increases lymphatic and venous drainage (Coutts, Toth, & Kaita, 1984). Research is needed to investigate the efficacy of the use of CPM as a treatment for hand edema reduction and to provide data on which to base treatment protocols.

The purpose of the present study was to investi-
gate the efficacy of the use of hand CPM in combination with limb elevation to reduce hand edema. The effects of 30 min of CPM of the digits with the limb elevated were compared with the effects of 30 min of limb elevation alone.

Limb elevation permits gravity to increase the rate of venous and lymphatic flow from the extremity. It also slows the rate of formation of edema fluid through hydrostatic reduction of venous pressure and a corresponding decrease in filtration pressure in the capillary bed (Abramson, 1965). Despite the widespread use and acceptance of limb elevation as a means of decreasing edema (Nicholas, 1977), there is little data documenting its effectiveness for patients with hand edema (Eccles, 1956; Salisbury et al., 1973). Sims (1986) found that in 25 nonfunctional subjects, a significant \( p < .001 \) mean decrease in ankle volume \((15.22 \text{ ml})\) occurred after 20 min of lower extremity elevation, thus supporting the effectiveness of limb elevation as a means of edema reduction.

Active motion of the hand is commonly recommended in combination with elevation of the affected extremity to reduce hand edema (Boyes, 1970; Brand, 1985; Hunter & Mackin, 1984). Active motion compresses adjacent veins and lymphatic vessels, thereby creating a pumping action that enhances venous and lymphatic flow (Guyton, 1977). Brand reported that postoperative hand patients showed greatly reduced hand volume following 30 min of elevation combined with active exercise.

Active motion, however, is not effective for reducing hand edema in patients whose hand function is impaired by paralysis, weakness, immobilization, stiffness, pain, fear, or poor compliance. The inability or unwillingness to perform active hand motion and effectively pump out the excess fluid has been proposed to be a major cause of persistent hand edema in patients with paretic upper extremities (Exton-Smith & Crockett, 1957) and in postsurgical hand patients (Milford, 1985). For these patient populations, therefore, passive motion may provide an effective alternative to active motion for the management of hand edema.

Passive motion, like active motion, is proposed to enhance venous and lymphatic flow from the hand through the use of a pumping action, which results from the compression of adjacent veins and lymphatic vessels (Guyton, 1977). Evidence of enhanced lymphatic drainage with passive motion has been observed in humans (McMaster, 1937) and in animals (Calnan, Pflug, Reis, & Taylor, 1970; Elkins, Herrick, Grindlay, Mann, & DeForest, 1953).

Although little documentation exists on the effects of passive motion on edema, it has been proposed that continuous passive motion, as provided by a CPM device, assists in edema reduction (Basso & Knapp, 1987; Coutts et al., 1984; Petrone & Calvanio, 1989). Coutts et al. postulated that the observed "virtual lack of edema" \((p. 127)\) in patients who received 2 weeks of CPM for a minimum of 20 hr per day immediately after total knee replacement was due to CPM assisting in venous and lymphatic flow. To test this postulate, Coutts et al. measured venous flow and intramuscular pressure during CPM use in 19 lower extremities after knee surgery. They documented a consistent surge of venous flow in the femoral vein and a simultaneous rise in the compartmental pressure of the posterior calf to a level above venous pressure with each flexion cycle of the leg. They suggested that CPM produced a pumping effect that prevented the accumulation of edema fluid in the patients who used CPM following knee replacement. Further support for the existence of a pumping effect produced by CPM was provided by O'Driscoll, Kumar, and Salter (1983) and Aratow et al. (1989).

Basso and Knapp (1987) compared the effects of CPM administered for a minimum of 20 hr per day with the effects of CPM administered for a maximum of 5 hr per day in patients following total knee replacement. Reductions in midpatellar circumference were found for both groups \((- 65 \text{ cm and } - 80 \text{ cm}, \text{ respectively})\), with no significant difference between the groups.

In 1989, Petrone and Calvanio reported the results of an unpublished study comparing hand volume reduction following 2 hr of hand CPM to hand volume reduction following 2 hr of compression wrapping for 10 hemiplegic subjects with hand edema. They found that the CPM resulted in a mean decrease of 19 ml in hand volume, which was significantly greater \((p < .001)\) than the mean reduction of 5.6 ml found following compression wrapping.

Given the lack of research documenting the effects of CPM on hand edema and the encouraging clinical reports of edema reduction associated with the use of CPM, the need for research is evident. On the basis of the assumption that both limb elevation and passive motion enhance venous and lymphatic drainage from the hand, it seems reasonable that CPM would be most effective for reducing hand edema when combined with limb elevation. To control for the effects of limb position as well as to investigate the ability of CPM to augment the effects of limb elevation on edema reduction, I compared the effects of limb elevation alone with the effects of CPM combined with limb elevation. On the basis of studies reporting edema reduction following treatment sessions lasting between 5 and 40 min (Brand, 1985; Flowers, 1988; Masman & Conolly, 1976; McKnight & Schomburg, 1982; Sims, 1986), I hypothesized that 30 min of CPM of the digits combined with limb eleva-
tion would result in a significantly greater reduction of hand edema, as measured by hand volume, finger circumference, and finger stiffness, than 30 min of limb elevation alone.

Method

A repeated-measures design was used with each of 16 subjects receiving both treatments. Eight of the subjects received elevation alone on one day and CPM with elevation on the next day (at the same time of day). The other 8 subjects received the treatments in the reverse order. During the subjects' participation in the study, their usual activities, including treatment for edema, were unaltered.

Subjects

Patients from four rehabilitation facilities who had visible hand edema more than 4 weeks after upper extremity injury or surgery or after the onset of upper extremity paresis were referred by their primary occupational therapist and asked to volunteer for the study. Eleven men and 5 women, ranging in age from 38 to 78 years, gave informed consent and completed the study.

No subjects had pain or limitation of motion in the fingers that precluded passive flexion of the fingers to within 1/2 in. of the palm. No subjects had any known upper extremity lymphatic blockage or a secondary condition (e.g., rheumatoid arthritis) that resulted in upper extremity edema. No subjects had unhealed wounds, infections, or unstable fractures in their edematous upper extremity.

Instrumentation

To ensure reliable measurement of hand volume, finger circumference, and finger stiffness, a precise protocol was developed for each measurement. Intrarater reliability was determined for each protocol with Pearson product-moment correlations for two successive measures of 10 normal hands (i.e., of 5 subjects).

Hand volume was assessed through the averaging of two successive volumetric measures (in milliliters) of the affected hand. The protocol was based on the research and recommendations of Devore and Hamilton (1968), Eccles (1956), McKnight and Schomburg (1982), and Waylett and Seibly (1981). Intrarater reliability for the measurement protocol on normal hands was $r = 1.0$.

A circumferential measure (in millimeters) was taken of the proximal phalanx of the most visibly edematous finger with the use of a tape measure. The intrarater reliability for this measurement protocol was $r = 1.0$.

A measure of finger stiffness was determined through the measurement of the degrees of passive range of motion of metacarpophalangeal flexion when a constant force of 200 g was applied to the proximal phalanx of the most visibly edematous finger for 5 sec (Brand, 1985). A finger goniometer was used to measure passive range of motion, and a force gauge was used to monitor the amount of force applied. The intrarater reliability for this measurement protocol was $r = .92$.

Procedure

Measurements were taken immediately before and after treatment in the following order: (a) finger circumference, (b) finger stiffness, and (c) hand volume. The amount of time required to take the measurements was similar for each subject across treatments, but varied among subjects from 12 to 30 min. At all times unaccounted for by measurement or treatment, the affected extremity was supported so that it was neither elevated nor dependent.

For the condition of elevation alone, the subjects were supine on a flat surface with the extremity positioned on a stand adapted to maintain the limb in approximately 30° of shoulder abduction, 30° of shoulder flexion, and 70° of elbow flexion. For the condition of CPM combined with elevation, the subjects were positioned in the same manner as for elevation alone while a CPM hand unit provided continuous passive flexion and extension of the index, middle, ring, and little fingers (see Figure 1).

During both treatments, the subjects' wrists were supported with the universal wrist splint provided with the CPM unit. Additionally, for both treatments,
the subjects were instructed to relax and not to move the elevated extremity.

Data Analysis

Scores for all 16 subjects and for the subgroup of 11 subjects with cerebrovascular accident (CVA) were analyzed separately. The mean change scores (pre-score - post-score) and mean percentage change scores [(mean change score/pre-score) X 100] for hand volume, finger circumference, and finger stiffness for elevation alone and for CPM with elevation were compared with the use of three 2 X 2 (i.e., one between factor and one repeated factor) mixed analyses of variance (ANOVAs). The between factor was Treatment Sequence and the repeated factor was Day (1 and 2). The treatment effect was tested in the interaction effect of sequence with day, which is essentially a test of the difference in the mean change scores for CPM with elevation versus elevation alone. This test is similar to a simple t-test comparing the mean change scores, but it uses a more precise error term, that is, the variance attributed to sequence and day are removed.

The probability level of .02 (.05/3) was selected as the criterion for significance, a level adjusted for the use of three planned ANOVAs (Rosenthal & Rosnow, 1984). Because this adjusted level is conservative and may lead to failure to reject the null hypothesis when it is, in fact, false (i.e., a Type II error), the effect size r was also calculated for each treatment effect. The effect size r is a measure that shows the magnitude of the difference between the two treatments. An r of .10 is a small effect, an r of .30 is a moderate effect, and an r of .50 is a large effect (Cohen, 1977).

Pearson product-moment correlations were calculated separately for each dependent measure and for each treatment to determine if a relationship existed between treatment outcomes (i.e., mean percentage change scores for hand volume, finger circumference, and finger stiffness) and the factors of (a) time in weeks after onset of diagnosis, which resulted in hand edema, and (b) amount of pretreatment edema ([pre-volume - unaffected hand volume]/unaffected hand volume) X 100.

Results

Findings for the Total Group

The mean change scores and mean percentage change scores for the dependent measures of the total group (N = 16) for both treatments are displayed in Table 1. The results of the ANOVAs and the effect sizes calculated on the mean percentage change scores are displayed in Table 2. Significant and large treatment effects were found for all three dependent measures. For this sample, the treatment of CPM with elevation resulted in a significantly greater reduction of hand edema than the treatment of elevation alone.

Sequence effects were not significant for the measures of hand volume or finger circumference. The sequence effect for the measure of finger stiffness [F(1,14) = 3.97, p < .03], however, approached the

### Table 1

<table>
<thead>
<tr>
<th>Measure</th>
<th>Elevation Alone</th>
<th>CPM With Elevation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand volume (ml)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>6.1</td>
<td>14.5</td>
</tr>
<tr>
<td>SD</td>
<td>9.5</td>
<td>8.4</td>
</tr>
<tr>
<td>Finger circumference (mm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>0.6</td>
<td>1.4</td>
</tr>
<tr>
<td>SD</td>
<td>0.6</td>
<td>0.9</td>
</tr>
<tr>
<td>Finger stiffness (degrees)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>0.5</td>
<td>5.8</td>
</tr>
<tr>
<td>SD</td>
<td>4.9</td>
<td>8.8</td>
</tr>
</tbody>
</table>

Note: CPM = continuous passive motion.

* Change score for hand volume and finger circumference = prescore - post-score; for finger stiffness, postscore = prescore. Thus, the higher the score, the greater the reduction in hand volume, finger circumference, and finger stiffness. Percentage of change score = (mean change score/pre-score) X 100.
significance level of .02 set for the ANOVA. This finding indicates that subjects who received CPM with elevation first tended to have a greater reduction in finger stiffness than did the subjects who received elevation alone first, which suggests a carryover of reduced stiffness following CPM with elevation. That the pretreatment measures of stiffness for Days 1 and 2 are similar for both sequences does not support the existence of a carryover effect, but does suggest that the effect was due to chance. The effect of day was not significant for any of the dependent measures, given the level of significance set for this study.

The results of the correlational analyses investigating the relationship between treatment outcomes and (a) time after onset and (b) amount of pretreatment edema are shown in Table 3. The coefficients relating outcome and time after onset showed a small to moderate positive relationship (the greater the time after onset, the greater the treatment effect) for reduction in hand volume and stiffness following elevation alone and for reduction in stiffness following CPM with elevation. Almost no relationship was found for hand volume or finger circumference following CPM with elevation or for finger circumference following elevation alone.

Correlation coefficients relating outcomes to amount of pretreatment edema show a moderate to large positive relationship (the greater the amount of pretreatment edema, the greater the treatment effect) for hand volume and finger circumference following CPM with elevation, but no relationship for these same measures following elevation alone. A moderate positive relationship was found between the amount of pretreatment edema and decreased stiffness following elevation alone, and a small positive relationship was found between these variables following CPM with elevation.

**Table 4**  
Change Scores for Hand Volume, Finger Circumference, and Finger Stiffness for the CVA Subgroup (n = 11)

<table>
<thead>
<tr>
<th>Measure</th>
<th>Elevation Alone</th>
<th>CPM With Elevation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Change Score</td>
<td>Percentage Change</td>
</tr>
<tr>
<td>Hand volume (ml)</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td></td>
<td>5.9</td>
<td>1.1</td>
</tr>
<tr>
<td>Finger circumference (mm)</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td></td>
<td>0.7</td>
<td>0.9</td>
</tr>
<tr>
<td>Finger stiffness (degrees)</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td></td>
<td>0.4</td>
<td>1.8</td>
</tr>
</tbody>
</table>

Note. CVA = cerebrovascular accident. CPM = continuous passive motion.

Mean change scores and mean percentage change scores for the dependent measures of the CVA subgroup (n = 11) are shown in Table 4. Results of the ANOVAs and the effect sizes calculated on the mean percentage change scores for this subgroup are shown in Table 5.

The ANOVAs showed no significant sequence effects or day effects. The treatment effects approached the conservative level of significance set for this study (.02) for the measures of hand volume (p < .03), finger circumference (p < .03), and finger stiffness (p < .06). In addition, the effect sizes for all three dependent measures were large (r > .50). The large effect sizes indicate a high degree of difference between the two treatments and suggest that the differences between the mean percentage change scores for the two treatments would have been significant at the .02 level if a larger sample had been used. For the 11 subjects with hemiplegia secondary to CVA, 30 min of CPM with elevation was more effective in the reduction of hand edema than was 30 min of elevation alone.

**Discussion**

The use of CPM as a method of hand edema reduction is a relatively new concept, and no data have been published documenting its efficacy. The report of a mean reduction of 19 ml in the hand volumes of 10
hemiplegic subjects following 2 hr of hand CPM (Petrone & Calvanio, 1989) is encouraging. The authors, however, did not control for the effects of limb position, which makes it difficult to separate the effects of the CPM from the well-documented (Sims, 1986) effects of limb position.

In the present study, 30 min of CPM with limb elevation resulted in a significantly greater reduction in hand edema than did 30 min of limb elevation alone. One can speculate that CPM augments the effects of elevation by creating a pumping action or a rhythmic compression of adjacent veins and lymphatic vessels (Cutts et al., 1984; O’Driscoll et al., 1983), thereby enhancing lymphatic and venous drainage from the hand.

That the findings for the total group (N = 16) were similar to the findings for the CVA subgroup (n = 11) suggests that CPM combined with limb elevation may be an effective treatment method to reduce hand edema for patients with hemiplegia after CVA. Further generalization of the results to specific patient populations is not possible, given the small sample size and the lack of homogeneity among the subjects' conditions. A common factor across all subjects, however, was an impaired ability to use the edematous hand for functional activity (15 subjects had hand paresis or paralysis, and 1 subject had limited hand use due to stiffness and pain accompanying shoulder-hand syndrome). CPM with limb elevation, therefore, may provide an effective alternative for those patients who, due to impaired hand function, are unable to effectively use active motion for edema reduction.

It is important to note that in this study and in the study by Petrone and Calvanio (1989), the measures of edema that were reduced following CPM treatment generally returned to pretreatment levels within 24 hr. Investigation of the long-term effects of CPM as well as of methods and protocols to improve the carryover from treatment to treatment are needed to establish whether CPM is effective for achieving more than a temporary reduction in hand edema. Research is also needed to investigate whether even temporary reduction of edema through the use of CPM is beneficial, particularly, whether treatment could significantly delay or prevent the process of tissue fibrosis and loss of range of motion that can occur with prolonged edema.

Two correlational analyses were performed to investigate factors that could potentially affect a person’s response to treatment. One factor was the amount of time after onset of the condition that resulted in the edema. Brand (1985) suggested that simple edema of low viscosity (e.g., edema caused by limb dependency or lack of muscle action) is easier to move and redistribute than the more viscous edema found with inflammation. He also suggested that edema becomes more viscous over time, particularly when tissues remain stagnant, thereby allowing invasion by protein cells and fibroblasts. This suggestion was supported by Exton-Smith and Crockett (1957), who collected data on the concentration of protein in fluids removed from 21 edematous hands of hemiplegic subjects and proposed that there was a correlation between protein content and time after onset of hemiplegia.

Assuming that there is a direct relationship between protein content, viscosity, and response to treatment for edema, it is reasonable to propose that the longer edema persists, the less responsive it is to treatment (a negative correlation between time after onset and treatment outcome). This postulate was not supported by the results of the regression analyses performed on the data in the present study. Either no relationship or small to moderate positive relationships were found between the weeks after onset of the condition that resulted in the hand edema and treatment outcomes.

The second potential factor affecting treatment outcome that was investigated was the amount of pretreatment edema. The results of the correlational analyses show a moderate to large positive relationship between the amount of pretreatment edema and...
treatment outcome for hand volume and finger circumference following CPM with elevation, but no relationship for these same measures following elevation alone. These findings suggest that CPM with elevation may be more effective for patients with large amounts of edema. More data are needed, however, to explore this concept.

Although all three measures of hand edema showed a greater reduction following CPM with elevation than following elevation alone, the measure that reflected the greatest difference in the subjects' responses to the two treatments was finger stiffness. I hypothesized that CPM would result in a greater reduction in hand edema, as measured by a decrease in finger stiffness. The magnitude of the result can only be explained, in part, by a reduction in edema. The decreased stiffness following CPM with elevation probably was also due to the well-known effect of passive motion on tissue lengthening (Sapega, Quednfeld, Moyer, & Butler, 1981). Although it is beyond the scope of this paper to address the effects of CPM on joint stiffness and range of motion, it is worth noting that increased range of motion and decreased stiffness from tissue lengthening are other potential benefits of CPM (Ketchum, Hibbard, & Hassanein, 1979).

Conclusion

The results of this study support the hypothesis that 30 min of CPM of the digits in combination with limb elevation results in a significantly greater reduction of hand edema than 30 min of limb elevation alone. The findings were similar for both the total group (N = 16) and the subgroup of subjects with hemiplegia secondary to CVA (n = 11), which suggests that CPM with limb elevation is an effective treatment for the reduction of hand edema in the hemiplegic patient. This study supports further investigation of the use of CPM as an adjunctive treatment modality for the reduction of hand edema, particularly for those patients who do not respond favorably to traditional treatments for edema reduction due to an impaired ability to move or use the hand.

Research is needed to (a) further document the efficacy of the use of CPM with limb elevation as a method of edema reduction; (b) collect data on the immediate, cumulative, and long-term effects of treatment; (c) develop optimal treatment protocols for specific patient populations as well as for specific characteristics of hand edema; and (d) investigate the reliability and validity of the measures of hand edema for patients with limb paralysis.

I recommend to those interested in replicating the study that they (a) use a larger sample size, (b) use a more homogeneous sample, (c) include only those subjects with moderate to severe edema, and (d) increase controls for subjects’ activity and limb position before treatment and between treatment days.

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References


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